BY ORDER OF THE COMMANDER

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Air Force Space Command

SPACE AND MISSILE SYSTEMS CENTER STANDARD

SPACE BATTERY

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FOREWORD

1. This standard defines the Government's requirements and expectations for contractor performance in defense system acquisitions and technology developments.

2. This new-issue SMC standard comprises the text of The Aerospace Corporation report number TOR-2004(8583)-5, Rev 1.

3. Beneficial comments (recommendations, changes, additions, deletions, etc.) and any pertinent data that may be of use in improving this standard should be forwarded to the following addressee using the Standardization Document Improvement Proposal appearing at the end of this document or by letter:

Division Chief, SMC/EAE
SPACE AND MISSILE SYSTEMS CENTER
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4. This standard has been approved for use on all Space and Missile Systems Center/Air Force Program Executive Office - Space development, acquisition, and sustainment contracts.

James Horejsi, Col, USAF
SMC Chief Engineer

Contents

1. Scope

1.1 Purpose

This report establishes standards for the development, testing, storage, handling, and usage of batteries for space vehicle, launch vehicle, and upper-stage vehicle applications. Compliance with this standard is intended to assure proper performance of batteries and to provide protection against preflight degradation and premature degradation during operational use on space, launch, and upper-stage vehicles.

1.2 Application

This report is intended for compliance in applicable space, launch, and upper-stage vehicle acquisition and development to incorporate common requirements and practices necessary to assure successful battery operation during space missions. This report is oriented toward general space battery standards and not toward standards that are more appropriate for specific battery technologies, such as nickel-hydrogen, silver-zinc, lithium-ion or nickel-cadmium, that will be issued in the future. Any future updates of this report will be provided in subsequent versions.

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2. Applicable Documents

Test Requirements for Launch, Upper-Stage, and Space Vehicles, 31 January 2004, Aerospace Report No. TR-2004(8583)-1, SMC-TR-04-17, Erwin Perl, editor.

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3. Definitions

3.1 Actual Battery Capacity

The actual battery capacity is measured in units of ampere-hour (for Ah capacity) and watt-hour (for Wh capacity). Actual Ah capacity for a specific condition is equal to the integral of the discharge current from the beginning of the discharge of a fully charged battery until the lower usable voltage limit is reached. Actual Wh capacity for a specific condition is equal to the integral of the product of discharge current and voltage from the beginning of the discharge of a fully charged battery until the lower usable voltage limit is reached. Actual battery capacity should be stated in both units to facilitate energy balance evaluations, thermal evaluations, and comparisons of different types of batteries; the condition (e.g., temperature) for the capacity measurement should also be stated.

Actual Ah capacity = $\int I_d \, dt$, where I_d, a positive value, is the discharge current, and the limits of integration are from full charge to the lower usable voltage limit.

Actual Wh capacity = $\int I_d V_d \, dt$, where I_d, a positive value, is the discharge current, V_d, a positive value, is the discharge voltage, and the limits of integration are from full charge to the lower usable voltage limit.

3.2 Battery

A battery is an assembly of battery cells or modules electrically connected (usually in series) to provide the desired voltage and current capability. Generally, the cells are physically integrated into either a single assembly (or battery) or into several separate assemblies (or modules). The battery may also include one or more attachments such as electrical bypass devices, heaters, strain gauges, pressure relief devices, temperature sensors, or thermal switches.

3.3 Cell or Battery Cell

A cell is a single unit device within one cell case that transforms chemical energy into electrical energy at characteristic voltages when discharged. Battery cells can be directly connected (usually in series) to form a battery. Battery cells can be connected in series or parallel to form a module; in such cases, the modules are connected (usually in series) to form a battery.

3.4 Cell Activation

The addition of electrolyte to a battery cell constitutes cell activation and starts the clock on cell, module, and battery service life. It is used to define the start of battery shelf life.

3.5 Cold Storage

Cold storage, for batteries that are not in use, is long-term storage where the temperature and humidity environments are controlled, and temperature is below ambient temperature.

3.6 Module Or Battery Module

A battery module is an assembly of series- or parallel-connected battery cells that are connected (usually in series) to form a battery.

3.7 Rated (or Nameplate) Battery Capacity

The rated (or nameplate) battery capacity is measured in units of ampere-hour, which is denoted by C(Ah) for Ah capacity, and watt-hour, which is denoted by C(Wh) for Wh capacity. The rated capacity shall be at least as great as the minimum capacity measured under the range of nominal mission charge control and load. C(Ah) shall be equal to or greater than, for the range of nominal mission charge control and load conditions, the integral of the discharge current from the beginning of the discharge of a fully charged battery until the lower usable voltage limit is reached. C(Wh) is equal to or greater than, for the range of nominal mission charge control and load conditions, the integral of the product of discharge current and voltage from the beginning of the discharge of a fully charged battery until the lower usable voltage limit is reached. The actual battery capacity under ground test conditions is expected to be greater than rated capacity since batteries may be more fully charged under ground test conditions, rated capacity envelopes the range of nominal mission charge control and load conditions, and capacity can degrade prior to mission use. Rated battery capacity should be stated in both units to facilitate energy balance evaluations, thermal evaluations, and comparisons of different types of batteries.

C(Ah) $\geq \int I_d \, dt$, where I_d, a positive value, is the mission discharge current, and the limits of integration are from full charge under mission charge control conditions to the lower usable voltage limit; this relation shall be valid for all nominal conditions.

C(Wh) $\geq \int I_d V_d \, dt$, where I_d, a positive value, is the mission discharge current, V_d, a positive value, is the discharge voltage, and the limits of integration are from full charge under mission charge control conditions to the lower usable voltage limit; this relation shall be valid for all nominal conditions.

3.8 Service Life

The service life of a battery, battery module, or battery cell starts at cell activation and continues through all subsequent fabrication, acceptance testing, handling, storage, transportation, testing preceding launch, launch, and mission operation.

3.9 Shelf Life Limit

Shelf life limit for a battery, module, or cell is the maximum allowed time from cell activation to launch. This includes any time in cold storage.

3.10 State of Charge

The state of charge (SOC) of a battery that has been charged at least to its rated capacity is the ratio of the rated battery capacity, minus capacity removed to the rated battery capacity expressed as a percentage. It can be expressed in terms of ampere-hours or watt-hours.

$$\mathrm{SOC(Ah)} = \left(\frac{\mathrm{C(Ah)} - \mathrm{C(Ah)}_{\mathrm{REMOVED}}}{\mathrm{C(Ah)}} \right) \mathrm{X}\ 100$$

$$\mathrm{SOC(Wh)} = \left(\frac{\mathrm{C(Wh)} - \mathrm{C(Wh)}_{\mathrm{REMOVED}}}{\mathrm{C(Wh)}} \right) \mathrm{X}\ 100$$

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4. Development Testing

4.1. Development Testing

Development testing shall be conducted for a new or modified battery design, new or modified module design, new or modified cell design, new application, or new supplier of cell, module, or battery. Development testing should be used to confirm life expectancy, performance and structural margins, dimensional requirements, compatibility to pre-launch, launch and space environments, manufacturability, testability, maintainability, reliability, and compatibility with system safety. Development tests should be conducted, when practical, over a range of operating conditions that exceeds the design range to identify margins in capability. Operating conditions include temperature and charge control conditions.

4.2 Charge Control Testing

Testing of a battery shall be performed to determine whether the charge control method and conditions are consistent with required battery capabilities. Control parameters to be used, such as voltage, temperature, or pressure, shall be characterized sufficiently for a flight-type battery to demonstrate a charge control design that will meet the requirements for all vehicle operations, including sun periods and contingencies.

4.3 Thermal Control Testing

Testing of a battery shall be performed to determine whether the thermal control method and conditions are consistent with required battery capabilities. Control parameters to be used, such as temperature and temperature gradients, shall be characterized sufficiently for a flight-type battery to demonstrate a thermal control design that will meet the requirements for all vehicle operations, including sun periods and contingencies.

4.4 Life Expectancy Confirmation

Confirmation of battery life expectancy shall be based upon battery life testing or a combination of analyses and confirmation of the life expectancy of battery materials and components, such as module, cell, electrical bypass devices, heaters, strain gauges, temperature sensors, or thermal switches. Confirmation of battery module life expectancy shall be based upon module life testing or a combination of analyses and confirmation of life expectancy of module materials and components, such as cell, electrical bypass devices, heaters, strain gauges, temperature sensors, or thermal switches. Confirmation of life expectancy of module and battery components (except for battery modules) shall be based on life testing.

4.4.1 Life Testing

Life testing of battery, module, or cell for service life expectancy confirmation shall be under a set of conditions that envelope the conditions preceding launch, mission battery loads, charge control methods and conditions, and temperatures. Test duration shall include margin to demonstrate the required battery reliability and confidence level from the number of test samples.

4.4.1.1 Real-Time Life Test

For launch vehicle and upper-stage vehicle applications, a battery, module, or cell life test used to confirm life expectancy shall be a real-time life test. For space vehicle applications, a battery, module, or cell life test used to confirm life expectancy can be a real-time life test.

4.4.1.2 Accelerated-Time Life Test

For space vehicle applications, a battery, module, or cell life test used to confirm service life expectancy can be a set of accelerated-time test that envelopes the mission loads, charge control methods and conditions, and temperatures. The time-acceleration factor for activated time prior to launch and the time-acceleration factor for the orbital mission duration portion of the service life can have different values. For cases where a time-acceleration factor has been established by previous life-test results to be valid for the mission conditions and duration, the established acceleration factor can be used. For cases where a time-acceleration factor has not been established by previous test results to be valid for the mission conditions and duration, the time-acceleration factor shall be based on a sound analysis of data and shall not be greater than two.

5. Qualification and Acceptance Testing

5.1 Qualification Test

Qualification tests shall be conducted to demonstrate that the design, manufacturing process, and acceptance program produce battery hardware that meet specification requirements with adequate margin to accommodate normal production variation, multiple rework, and test cycles. In addition, the qualification tests shall validate the planned acceptance program, including test techniques, procedures, equipment, instrumentation, and software. Each type of battery, module, or cell that is to be acceptance tested shall undergo a corresponding qualification test. A qualification test specimen shall be exposed to all applicable environmental tests in the order of the qualification test plan.

5.1.1 Test Hardware

The hardware subjected to qualification testing shall be produced from the same drawings, using the same materials, tooling, manufacturing process, and level of personnel competency as used for flight hardware. Ideally, a qualification battery, module, or cell would be randomly selected from a group of production items.

5.1.2 Qualification Test Levels and Duration

To demonstrate margin, the qualification environmental conditions shall stress the qualification hardware to more severe conditions than the maximum conditions that might occur during service life. Qualification testing, however, should not create conditions that exceed applicable design safety margins or cause unrealistic modes of failure. The qualification test conditions should envelop those of all applicable missions. Qualification test levels shall be consistent with those described in Section 2.

5.2 Qualification Tests Required

Test	Launch Vehicle Application	Upper Stage Vehicle Application	Space Vehicle Application
Inspection	R	R	R
Specification Performance	R	R	R
Leakage	R	R	R
Shock	R	ER	ER
Vibration or Acoustic	R	R	R
Acceleration/Loads	ER	ER	ER
Thermal Cycle	R	R	R
Thermal Vacuum	R	R	R
Climatic	ER	ER	ER
Proof Pressure	R	R	R
Electromagnetic Compatibility	ER	ER	ER
Life (see 4.4.1)	R	R	R
Burst	R (1)	R (1)	R

R Required
ER Evaluation Required
NR Not required
(1) Not required if component contains a pressure relief device.

5.3 Acceptance Tests

Acceptance tests shall be conducted to demonstrate the acceptability of each flight battery, module, or cell to meet performance specification and demonstrate error-free workmanship in manufacturing. Acceptance testing is intended to stress screen items to precipitate incipient failures due to latent defects in parts, processes, materials, and workmanship. The acceptance test conditions shall envelop a composite of the worst-case applications. When a destructive test is to be performed, it shall be performed on representative cells from each flight lot.

5.3.1 Acceptance Test Levels and Durations

To demonstrate workmanship, the acceptance environmental conditions shall stress the hardware to the maximum conditions expected for all flight events, including transportation and handling. Acceptance test levels shall be consistent with those in Section 2.

5.3.2 Acceptance Test Required

Test	Launch Vehicle Application	Upper Stage Vehicle Application	Space Vehicle Application
Inspection	R	R	R
Wear-in	ER (1)	ER (1)	ER
Specification Performance	R	R	R
Leakage	R	R	R
Shock	ER (1)	ER (1)	ER
Vibration or Acoustic	ER (1)	ER (1)	R
Thermal Cycle	ER (1)	ER (1)	ER
Thermal Vacuum	ER (1)	ER (1)	R
Proof Pressure	R	R	R (2)
Proof Load	R	R	-
EMC	ER (1)	ER (1)	ER
Life (see 4.4.1)	R (3)	R (3)	NR

R Required
NR Not Required

(1) These tests are destructive to silver-zinc batteries due either to stress level or duration. However, they have been denoted as ER to allow use of other types of batteries for this application.
(2) Required for batteries with pressure vessels, otherwise ER.
(3) Life testing is required on representative cells from each manufacturing lot basis of silver-zinc batteries due to expectable manufacturing variations.

6. Storage And Handling

6.1 Battery Storage and Handling

The requirements set forth in this section apply to the storage and handling of batteries during ground activities preceding launch. Cells or modules can be stored prior to battery assembly to minimize degradation. Following completion of assembly, batteries for operational use shall successfully complete acceptance testing and then either be prepared for installation on a vehicle or placed in a cold storage. Storage, handling, and conditioning shall be in accordance with practices that minimize preflight degradation and comply with all safety requirements for the facility.

6.1.1 Storage

Batteries, modules, or cells that are not in use shall be placed in cold storage, whenever practicable, in an appropriate state-of-charge and maintained in cold storage, with temperature and humidity maintained in an appropriate range. A battery that is not in use shall not remain outside of cold storage for a period exceeding 45 days unless it has been previously qualified (including service life verification) for longer periods of time at ambient conditions. Batteries, modules, or cells not in use and not in cold storage shall be stored inside a building under a controlled temperature and humidity. Even if properly stored, batteries shall not be used for flight if the time between battery cell activation and launch exceeds the specified activated shelf life.

6.1.2 Discharge with a Battery Conditioning Module

When discharged is the appropriate storage condition for a battery, the discharge of batteries to prepare for storage shall be accomplished with a battery conditioning module that will discharge the battery or individual cells at specified control rates. As a safety feature, devices shall be incorporated in the design of battery conditioning modules to accommodate the discharge of the battery at any state-of-charge without causing any damage to the battery or vehicle, including the prevention of any battery cell voltage reversals.

6.1.3 Shorting Plugs

When discharged, shorted is the appropriate storage condition for a battery, shorting plugs shall be used to maintain a shorted condition across the terminals of each individual cell. As a safety feature, shorting plugs shall be designed to accommodate an inadvertent connection to a charged battery, up to its rated capacity, without causing any damage to any component of the battery or to the vehicle. Shorting plugs shall also be designed to prevent any battery cell voltage reversals. The design shall provide a means for verifying that the inadvertent connection protection features are operational.

6.1.4 Handling Fixture

A handling plate shall be used after the battery is assembled and prior to installation of the battery on the vehicle. The handling plate shall protect from damaging the battery and any other structural or thermal interface of the battery with the vehicle. The handling plate shall be removed when the battery is installed on the vehicle.

6.1.5 Terminal Cover

An easily attachable and removable non-conducting cover shall protect the battery's terminals and connectors to the vehicle wiring harness after its assembly until just prior to its installation on the vehicle. Optionally, the cover may remain in place for some or all of the vehicle launch preparation, but shall be removed prior to launch.

6.1.6 Connector Saver

A connector saver shall be used during all testing prior to battery installation on the vehicle to avoid repeated connecting and disconnecting of the flight connector. The connector saver shall interface between the battery flight connectors and any mating test or ground support equipment cables. The connector saver shall be removed just before storage or space vehicle installation.

6.1.7 Shipment to Vehicle Fabrication and Assembly Site

Batteries shall be transported from the battery manufacturer’s factory location or storage location to the vehicle fabrication and assembly site in the appropriate storage state. Batteries shall be maintained between –10°C and +25°C during handling and transportation if it is practical to do so. In no case shall the upper temperature limit for a battery exceed +30°C.

6.1.8 Conditioning Prior to Installation On the Vehicle

A battery in the storage condition will be conditioned prior to installation on the vehicle according to the steps and conditions of the battery-conditioning plan. Those steps shall include the verification of the capability of meeting battery operating and capacity requirements either by directly testing the flight article or, for primary or non-recharged batteries, by testing of representative cells from the flight cell lot.

6.1.9 Minimum Use of Flight Batteries for Testing of Vehicle

To maximize on-orbit performance, the actual batteries to be used for flight shall not be installed or used for vehicle-level integration or acceptance tests at the vehicle fabrication and assembly site, except as may be necessary for nonoperational tests such as spin balance. Test batteries that are equivalent in configuration to the flight batteries, and that have passed battery flight-level acceptance tests, shall be used for space vehicle level integration and acceptance testing. Ground power supplies may be used for launch vehicle and upper-stage vehicle testing.

6.1.10 Transportation to Launch Site

Flight batteries may be installed in the vehicle before it is shipped to the launch site or they may be shipped separately and installed at the launch site. In either case, the batteries shall be shipped in a storage-appropriate state. Vibration and shock loads during handling, transportation, and installation shall not exceed the levels specified in the battery specification. Batteries shall be maintained between –10°C and +25°C, if it is practicable to do so, during handling, transportation, and installation. In no case shall the upper temperature limit for a battery exceed +30°C during handling, transportation, and installation. The battery temperature environment shall be continually monitored and recorded during transportation.

6.1.11 Records

Records documenting the flight accreditation status of batteries shall be maintained. These records shall provide traceability from production of the battery, through final installation in the vehicle, and on through to launch. The records shall indicate changes in battery location, status, use, storage time, or any conditions that could affect reliability or performance. Time-correlated records shall be maintained indicating battery charge or discharge current, battery voltage, and temperature to a sufficient accuracy to allow an assessment of potential degradation.

6.1.12 Not for Flight Marking

Batteries that by intent, by usage, or by material disposition are not suitable for use in flight, and which could be accidentally substituted for flight or flight spare hardware, shall be red tagged or striped with red paint, or both, to prevent such substitution. The red tag shall be conspicuous and marked “NOT FOR FLIGHT.” The red paint shall be material compatible, and the stripes unmistakable.

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7. Launch and On-Orbit Operations

7.1 Battery Monitoring Preceding Launch

Battery voltage, module voltage (when applicable and available), cell voltage (when available), current, battery temperature, module temperature (when applicable), and internal pressure (when available) shall be monitored periodically after battery installation on the vehicle up to the final terminal countdown. These data shall be evaluated to provide state-of-health verification of the electrical systems prior to launch. Pass/fail criteria shall be applied prior to and during the terminal countdown to abort the launch when malfunctions occur in launch-critical batteries.

7.2 Charge Control

Normal battery charging and control procedures, and contingency procedures, shall be prepared based upon test data obtained during vehicle, battery, module, and cell development testing. These documented procedures shall be the basis for battery operations and controls at the launch site and while on orbit.

7.3 Temperature

Battery temperatures throughout the orbital lifetime shall be maintained in the appropriate range based upon test data obtained during vehicle, battery, module, and cell development testing. Control and contingency procedure to maintain battery temperature within the required range shall be the basis for battery operations and control while at the launch site and on orbit.

7.4 On-orbit Battery Monitoring

Space vehicle battery voltage, module voltage (when modules are part of a battery), cell voltage (when available), current, battery temperature, module temperature (when modules are part of a battery), and internal pressure (when available) shall be monitored periodically during flight, and all sun (solstice) and eclipse operations. These data, together with depth of discharge performance, shall be summarized, trended, and evaluated to provide performance trends and be a basis for on-orbit operations.

SMC Standard Improvement Proposal

INSTRUCTIONS

1. Complete blocks 1 through 7. All blocks must be completed.
2. Send to the Preparing Activity specified in block 8.

NOTE: Do not be used to request copies of documents, or to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements. Comments submitted on this form do not constitute a commitment by the Preparing Activity to implement the suggestion; the Preparing Authority will coordinate a review of the comment and provide disposition to the comment submitter specified in Block 6.

SMC STANDARD CHANGE RECOMMENDATION:	**1. Document Number**	**2. Document Date**

3. Document Title	

4. Nature of Change
(Identify paragraph number; include proposed revision language and supporting data. Attach extra sheets as needed.)

5. Reason for Recommendation

6. Submitter Information

a. Name	**b. Organization**
c. Address	**d. Telephone**
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8. Preparing Activity	Space and Missile Systems Center AIR FORCE SPACE COMMAND 483 N. Aviation Blvd. El Segundo, CA 91245 Attention: SMC/EAE